3 POLICY AND SYSTEM MANAGEMENT COMPONENTS

3.1 LAKE OKEECHOBEE

Introduction

The name "Okeechobee" was derived from the Seminole Indian words "Oki" (water) and "Chubi" (big), and appropriately translates into "big water." Lake Okeechobee (LOK), the second largest freshwater lake lying entirely within the continental United States of America, occupies a surface area of approximately 728 square miles and has an average depth of 9 feet. Figure 3.1.1 shows the stage-area-storage relationships for Lake Okeechobee. The primary uses of LOK water are: (1) water supply to the Everglades Agricultural Area (EAA); (2) backup water supply to the Lower East Coast Service Areas; (3) water supply to adjacent municipalities (Belle Glade, Pahokee, Clewiston and Moore Haven; (4) bird and wildlife feeding ground; and (5) recreational (e.g., fishing and boating). Lake stages are controlled for the purpose of: (1) environmental protection and enhancement of the lake littoral zone (vegetation zone along the peripheral lake areas) and the Everglades; (2) flood protection of adjacent areas; (3) water supply to agricultural and urban users; and (4) protection of the St. Lucie and Caloosahatchee estuaries. The primary inflows to LOK are the Kissimmee River, Fisheating Creek, Taylor Creek/Nubbin Slough, Indian Prairie and Harvey Pond Canals. Its primary outlets are the Caloosahatchee River, St. Lucie River, Miami Canal, North New River Canal, Hillsboro Canal, West Palm Beach Canal and L-8 Canal.

Lake Okeechobee Water Budget

In the South Florida Water Management Model, Lake Okeechobee is simulated as a lumped hydrologic system as contrasted to the majority of the model domain where a distributed system of 2-mile by 2-mile grid cells is used (refer to Sec. 1.3). Only one water level is associated with the lake at any given time step. LOK is simulated using a water budget or mass balance approach using the modified-delta storage method (Trimble, 1986).

For each daily time step the water budget equation is solved for Lake Okeechobee. This equation relates the change in storage within the lake as a control volume, and incoming and outgoing flows for the same control volume. Mathematically, lake hydrologic components (rainfall, evapotranspiration and seepage) and managed flows (structure discharges) account for changes in lake storage. A generalized form of this equation can be written as:

$$S_{t+1} = S_t + Inflows_t - Outflows_t \qquad (3.1.1)$$

where:

S_{t+1} = storage in the lake at the next time step, (ac-ft);
S_t = storage in the lake at the current time step, (ac-ft);
$Inflows_t$ = volume flux into the lake (e.g. rainfall, levee seepage, structure discharge) during the current to the next time step, (ac-ft); and

Outflows$_t$ = volume flux out of the lake (e.g. evapotranspiration, levee seepage, structure discharge) during the current to the next time step, (ac-ft)

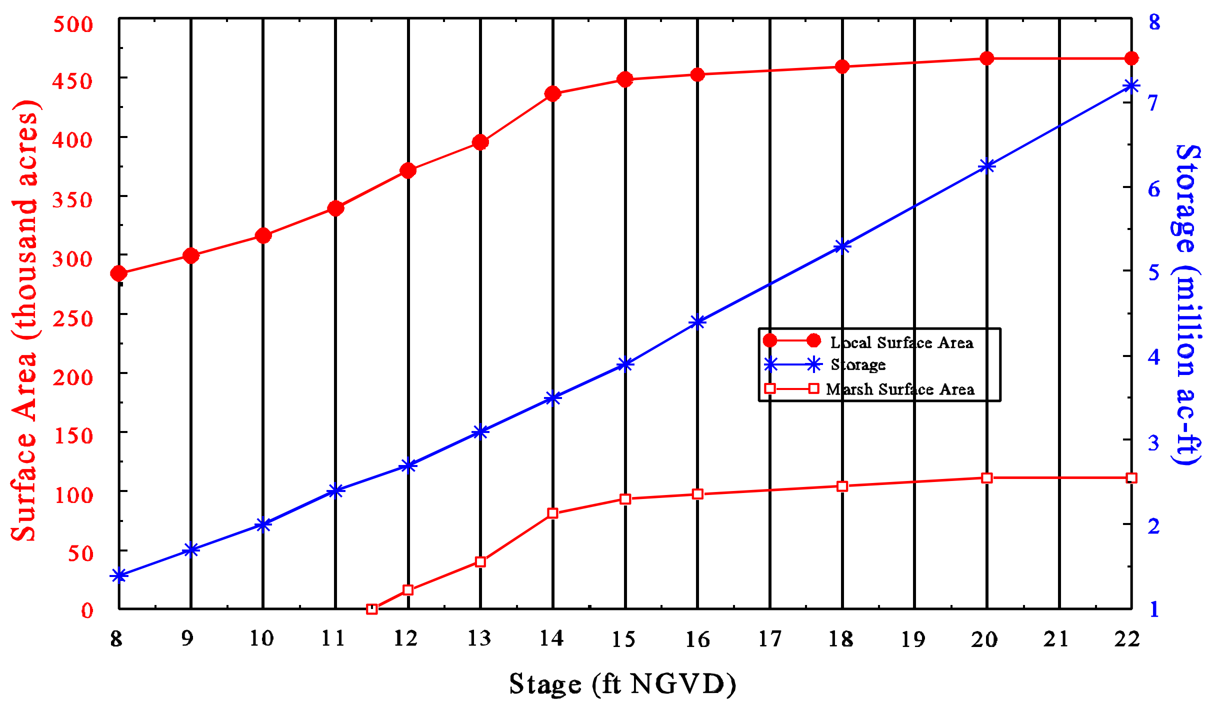


Figure 3.1.1 Lake Okeechobee Stage-Area-Storage Relationships

Management rules or operational policies dictate the amount, spatial distribution and timing of discharges through all lake water control structures which, in turn, determine the variation of lake storage. Given lake storage, the corresponding lake water surface area can be obtained via an area-storage relationship. Water surface area, on the other hand, is directly proportional to lake evapotranspiration. Given a fixed set of rainfall conditions and different management/operational scenarios, one can assess the different impacts of these scenarios on the other components of the lake water budget.

Rainfall in Lake Okeechobee is discussed in Sec. 2.1. Net levee seepage and regional groundwater movement in the lake are assumed to be small relative to the other hydrologic components of the lake water budget and are, therefore, not calculated in the model. Studies by Meyer and Hull (1969), and Shaw (1980) indicate that seepage rates range from 0.1 to 0.9 cfs/mile/ft. Evapotranspiration is estimated by relating pan evaporation to ET measured on lake marsh and open water areas. A detailed discussion of how ET is calculated in the model appears in Sec. 2.2. Runoff generated from surrounding drainage basins, e.g. Fisheating Creek and smaller culverts around the levee system that encloses the lake, may flow unregulated and/or unmeasured into the lake. Likewise, water withdrawal for irrigation purposes may also be unrecorded and thus, cannot be directly accounted for in the water budget equation. For generating historical water budgets, the problem is compounded by the lack of reliable continuous data at some key structures. In this situation historical flows are estimated by empirical methods.

In simulating a particular management/operational scenario for Lake Okeechobee one may be interested in changes (deviation from history) to a few structure discharges, i.e., only through the lake structures that will be impacted by the particular management/operational scenario. By taking this into consideration as well as the fact that some water budget components are relatively small compared to others, SFWMM assumes that runoff generated from most drainage basins north of the lake will not deviate from their historical values for any scenario run.

Modified-Delta Storage Method

The model uses the **modified-delta storage** method (Trimble, 1986) to perform a daily simulation of Lake Okeechobee stage. The following discussion will enable the reader to understand the concept behind the method as it relates to daily Lake Okeechobee stage calculation.

By definition, the modified-delta storage term represents the total contribution of water budget components that are assumed not to change from what has happened historically. The static nature of these components can be attributed to several factors: 1) the management/operational scenario being analyzed may not significantly impact, if at all, those particular components; 2) even if they do, the components themselves may be too small in magnitude in comparison with the others such that neglecting them may be a reasonable assumption; and 3) we have no means of quantifying them within reasonable certainty.

The *generalized* water budget (mass balance) equation for Lake Okeechobee may be written as a function of change in storage or delta storage (delS):

$$delS = Inflows - Outflows \tag{3.1.2}$$

where:

delS = $S_{t+1} - S_t$ = change in storage from the current to the next time step;
S_t = storage at the current time step t;
S_{t+1} = storage at the next time step t+1;
Inflows = volume of water entering the lake (via rainfall or structure flows) between time step t and t+1; and
Outflows = volume of water leaving the lake (via evapotranspiration or structure flows) between time step t and t+1.

All budget terms (and their components: rainfall/evapotranspiration/structure flows) can be partitioned into two categories: a subset of components that will be the same as historical (superscript *hist*) and a second subset of simulated components that will differ from historical (superscript *sim*). The need to combine historical and simulated components in the lake water budget will be explained later. Neglecting levee seepage and groundwater flow, Eq. (3.1.2) becomes:

$$delS^{sim} = [\ Inflows^{hist} + Inflows^{sim}\ ] - [\ Outflows^{hist} + Outflows^{sim}\ ] \qquad (3.1.3)$$

where:

$Inflows^{hist} = RF^{hist} + qin^{hist}$;
$Inflows^{sim} = qin^{sim}$;
$Outflows^{hist} = qout^{hist}$; and
$Outflows^{sim} = ET^{sim} + qout^{sim}$.

Rearranging, the water budget equation for Lake Okeechobee becomes:

$$delS^{sim} = [\ qin^{sim} - qout^{sim} - ET^{sim}\ ] + MDS \qquad (3.1.4)$$

where:

$$MDS = RF^{hist} + qin^{hist} - qout^{hist} \qquad (3.1.5)$$
$= $ modified-delta storage.

The MDS term represents the arithmetic sum of all water budget components that are assumed not to deviate from one model run to another; it appears on the right-hand-side of the water budget equation, Eq. (3.1.4). A lake water budget based on a model run shows the relative influences of the different hydrologic components on lake storage. Also, by comparing two lake water budgets (based on two model runs), one can also infer relative impacts of the different model inputs to the two model runs on the overall lake hydrology.

The current form of the modified-delta storage term [Eq. (3.1.5)] requires historical rainfall and some historical structure inflows and outflows for Lake Okeechobee, i.e. components in the lake water budget that, in the course of a simulation run, are assumed to repeat in history even with alternative lake operating conditions. Historical rainfall record is readily available from the District hydrologic database. However, the last two terms in Eq. (3.1.5) may be uncertain or unknown, and thus, difficult to obtain or even estimate. Operations of many local drainage basin in the periphery of Lake Okeechobee remain unrecorded or highly uncertain (e.g., flows from Fisheating Creek) to date. Equation (3.1.5) serves the purpose of defining the modified-delta storage term. However, an alternative form of the MDS term, one that is easier to calculate, is used in the model. Its derivation follows.

Initially, consider a *historical* water budget for Lake Okeechobee. Again, we can partition the components of the historical water budget equation into two categories: components that will not change for any anticipated management/operational scenario to be evaluated in the future (subscript *NC*) and components that will change given the same scenario (subscript *C*). The equation becomes:

$$(delS^{hist})_C = [(qin^{hist})_{NC} + (qin^{hist})_C + (RF^{hist})_{NC}] - [(qout^{hist})_{NC} + (qout^{hist})_C + (Et^{hist})_C] \qquad (3.1.6)$$

or

$$(delS^{hist} - qin^{hist} + qout^{hist} + ET^{hist})_C = (RF^{hist} + qin^{hist} - qout^{hist})_{NC} \quad (3.1.7)$$

Note that the right-hand-side of the last equation is the same modified-delta storage term defined in Eq. (3.1.5) but, this time, derived from a historical water budget perspective. Therefore, an alternative form of the generalized water budget equation for Lake Okeechobee becomes

$$delS^{sim} = [qin^{sim} - qout^{sim} - ET^{sim}] + MDS \quad (3.1.8)$$

where:

$$\begin{aligned} MDS &= delS^{hist} - qin^{hist} + qout^{hist} + ET^{hist} \quad (3.1.9) \\ &= \text{modified-delta storage.} \end{aligned}$$

All terms in Eqs. (3.1.5) and (3.1.9) are historical values. The main difference in those two equations is that in the former, all terms represent budget components not expected to change in future simulation runs, while in the latter, all terms represent budget components that will probably change due to one or more proposed operational strategies which may impact the lake. The South Florida Water Management Model uses the form of the MDS term as defined in Eq. (3.1.9) and calculates the lake storage (or stage) change from one time step to the next using Eq. (3.1.8).

The modified-delta storage term *represents* the sum of all historical water budget components that are assumed not to change given a different (from what has historically been used) set of rules for managing lake water [Eq. (3.1.5)]. It is, however, *calculated* in terms of the complement historical water budget components [Eq. (3.1.9)] i.e., components that will be affected by different sets of lake water management rules. It follows then that this method requires one to know the historical values (either by field measurement or estimation) of all water budget components that are expected to deviate (from history) prior to being evaluated for a particular scenario run. The modified-delta storage term can also be viewed as the net effect of historical inflows being taken out and historical outflows being put back into the lake due to the fact that these flow components may have come in or left the lake (in terms of quantity, distribution and timing) differently had a different (from history) management/operational rule been in place.

The sum of the individual components of the modified-delta storage term is calculated off-line, stored in a DSS (USACE, 1994) format, and used as input to the model on a daily basis. The specific components of MDS used in all SFWMM simulations are defined as follows (the superscript hist which apply to all components is dropped for simplicity):

$$\begin{aligned} MDS = {} & delS + ET + S77 + S308 + L8 + S352 \\ & + (S351 - S2)_{nnr\text{-}hlsb\_canal} + (S354 - S3)_{miami\_canal} \\ & + (298_{districts\_dmd} - 298_{districts\_ro}) + (S4_{basin\_dmd} - S4_{basin\_ro}) \\ & + (S236_{basin\_dmd} - S236_{basin\_ro}) \\ & - S65E + S235_{outflow} + SEM_{dmd} \quad (3.1.10) \end{aligned}$$

All SFWMM simulations include the MDS term, a historical or known component of the water budget for Lake Okeechobee. Non-historical or simulated components of the water budget for the lake are calculated based on LOK operating rules. The combination of historical and non-historical components in the lake water budget makes it unnecessary to calculate all inflows/outflows to the lake, especially those with high uncertainties. For example, runoff via Fisheating Creek is considered the second largest single tributary (next to Kissimmee basin inflows) into the lake. One difficulty in estimating inflows from this basin is that flows are measured at Palmdale station which is located on the upper Fisheating Creek basin, several miles upstream of the confluence of the creek to the lake. By assuming that lake inflows from Fisheating Creek remain unchanged, i.e. unaffected by different scenario runs of the model, the current form of the MDS term [Eq. (3.1.10)] does not require an estimate of the historical discharges from the entire basin drained by the creek.

As mentioned earlier, Lake Okeechobee is simulated in the South Florida Water Management Model as a lumped hydrologic system. A flat or horizontal pool is assumed at each time step. However, lake ponding depths can be plotted spatially by subtracting lake bathymetry from the water level within the protective levee that defines the lake outer boundary. By displaying lake bathymetry into 2-mile square grid cells (Fig. 1.3.5), the lake and the overland/groundwater computational grid cells can be jointly represented in a single ponding depth map.

Management Processes

Water levels in Lake Okeechobee are managed through regulatory (flood control) and non-regulatory releases. Regulatory releases are made according to a regulation schedule, established by the U.S. Army Corps of Engineers (Corps) in conjunction with the South Florida Water Management District (District) and other public entities, to ensure that the integrity of the peripheral levee is not compromised due to high water levels. The regulatory level for Lake Okeechobee ranges from 15.65 ft NGVD in late May to 16.75 ft NGVD on October 1. The summary of the regulatory rules as set forth by the Corps is given in Fig. 3.1.2.

Non-regulatory releases are made to meet: (1) water supply requirements of the Lower East Coast Service Areas (LECSAs); (2) agricultural/irrigation demands in the Lake Okeechobee Service Area (LOSA); and (3) environmental needs of the St. Lucie and Caloosahatchee estuaries, the Water Conservation Areas (WCAs), and the Everglades National Park (ENP). These releases are sent to areas in the system that may need water for irrigation (e.g., EAA), saltwater intrusion control (e.g., canals in the Lower East Coast), domestic use (e.g., some lakeside communities), backup water supply (e.g., LEC service areas), and optionally, environmental enhancement (e.g., estuaries and Water Conservation Areas). Currently, there are no detailed and comprehensive policy governing lake environmental release. The model, however, has the capability to make this type of lake releases based on meeting stage and flow targets (minimum flows and levels), and in conjunction with other proposed infrastructures in the system such as Storm Water Treatment Areas (STAs), Aquifer Storage and Recovery (ASR) technology, and impoundments like reservoirs or buffer (marsh) areas (refer to Sec. 3.3). Table 3.1.1 summarizes the operational rules governing Lake Okeechobee as implemented in the model. The order by which the release type is presented in this table determines the sequence of deliveries as simulated in the model.

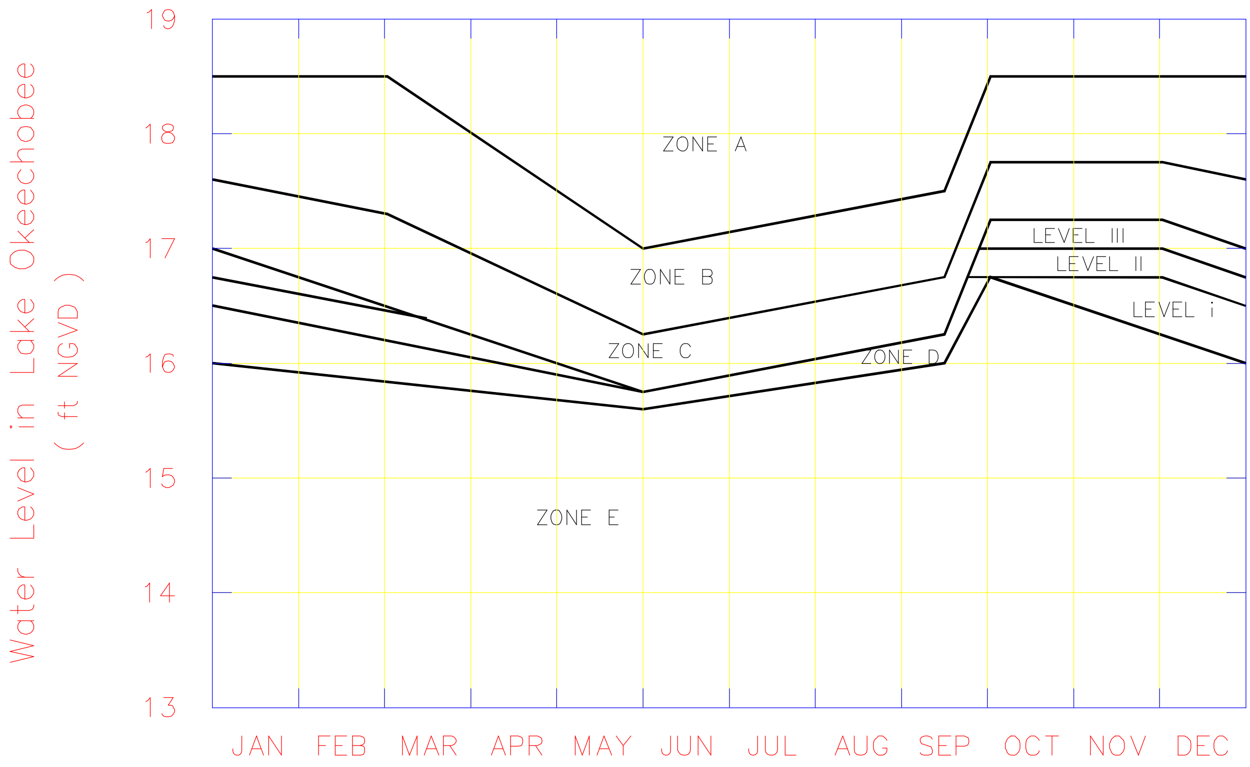
Table 3.1.1 Lake Okeechobee Operations in the South Florida Water Management Model

RELEASE TYPE	TRIGGER	ACTION(S)	DESTINATION	EXCEPTIONS	SUBROUTINES USED	COMMENTS
WATER SUPPLY:						
EAA	Volumetric based on crop ET requirement	LOK supplements rainfall and local storage to meet total ET requirements	EAA via S354, S351, S352 & C#10A	Delivery is subject to supply side management criteria and structure capacity limitations	AGAREA - supplemental requirement from LOK SSM ROUTE - determine delivery	ET req = K * PET PET: Penman Monteith method
Lower East Cost (Domestic use, Industrial use, Agricultural use)	Net LECSA demands minus WCA contribution	LOK as back-up source. Delivery occurs when available water in WCA relative to its Afloor elevation: is less than demand in LEC service area	LEC service areas via EAA and WCA conveyance systems	If runoff from EAA sufficient to meet LEC demands	AGAREA (EAA runoff) WSNEEDS (LEC demand) LAKEWCA (determine delivery from LOK)	WCA Floor elevations WCA-1: 13.0 WCA-2A: 10.5 WCA-3A: 7.5 Floor elevations represented by canal stages
S-4 & S-236 basins	Volumetric: demand is area weighted, based on ratio of area of these basins to area of Miami Canal Basin	Volumetric transfer from LOK without conveyance limitations	S-4 & S-236 Basins	Delivery subject to supply - side management (SSM)	SSM AGAREA LAKEWCA	
Caloosahatchee & St. Lucie	Demand time series	Releases if demand exceeds local basin runoff	Caloosahatchee and/or St. Lucie Rivers	Subject to SSM	CALOOS STLUCIE LAKEWCA	Demand time series data in input file dmdro2x2.dss
Northern Rim (Seminole Indians)	Demand time series	Volumetric transfer	Appropriate basin	Subject to SSM	SSM LAKEWCA	Demand time series data in input file dmdro2x2.dss

Table 3.1.1 (*cont.*) Lake Okeechobee Operations in South Florida Water Management Model

RELEASE TYPE	TRIGGER	ACTION(S)	DESTINATION	EXCEPTIONS	SUBROUTINES USED	COMMENTS
ENVIRONMENTAL:						
Everglades	NSM (or other) stage targets	If simulated stage at trigger location(s) is less than target stage(s), deliver water at maximum available capacity	• WCA-3A via Miami Canal first, then NNRC if desired • WCA-2A via Hillsboro Canal • WCA-1 via WPB Canal		MAIN LAKEWCA	Stage targets in input file import.nsm43
Estuary	Demand time series	If estuary demands exceed local basin runoff, supplement water to meet remaining demand	Caloosahatchee and/or St. Lucie Rivers		CALOOS STLUCIE	Demand time series data in input file dmdro2x2.dss
ASR INJECTION:*						
	LOK stage adjusted for water supply and environmental releases, and available storage in associated reservoir. Adjusted LOK stage compared with ASR injection line	Deliver water to associated reservoir(s) subject to conveyance capacity and available storage in reservoir	Appropriate reservoir, then injected into ASR wells from reservoir. Deliver to RES/ASR systems in EAA first, then to Caloosahatchee or St. Lucie	• If LOK stage below regulatory zone D and environmental demands in Everglades and WS demands in LEC exist	ASR-INPUT STASTOR LAKEWCA STAOUT ASR RESASR_SIM	ASR system properties in input file asrinput.dat
REGULATORY:						
	LOK stage adjusted for water supply, and environmental releases, and ASR injection, if applicable	Delivery of water according to operational rules	1. WCAs Basins: a. WCA-1 via WPB Canal b. WCA-1 via Hillsboro Canal c. WCA-2A via NNR Canal d. WCA-3A via Miami Canal (sequence can be specified by user) 2. Caloosahatchee & St. Lucie Estuaries	Dry Season (to the south): if demand in EAA exceeds conveyance capacity; or if runoff exceeds operational capacity Wet Season (to the south): if runoff or demand in EAA exceeds operational capacity or Everglades does not need water (optional)	LAKEWCA	In choosing a regulatory schedule, one must consider environmental, water supply and flood control impacts.

* Water above regulation schedule is assumed to be available for injection into Aquifer Storage and Recovery (ASR) wells.



ZONE	AGRICULTURAL CANALS (2)	CALOOSAHATCHEE RIVER (2)	ST. LUCIE CANAL
A	PUMP MAX. PRACTICABLE TO WCAs	UP TO MAX. CAPACITY AT S-77	UP TO MAX. CAPACITY AT S-80
B (1)	MAX. PRACTICABLE TO WCAs	6,500 CFS AT S-77	3,500 CFS AT S-80 (3)
C (1)	MAX. PRACTICABLE TO WCAs	UP TO 4,500 CFS AT S-77	UP TO 2,500 CFS AT S-80 (3)
D	MAX. PRACTICABLE TO WCAs	MAX. NON-HARMFUL DISCHARGES TO ESTUARY WHEN STAGE RISING	MAX. NON-HARMFUL DISCHARGES TO ESTUARY WHEN STAGE RISING
E	NO REGULATORY DISCHARGE	NO REGULATORY DISCHARGE	NO REGULATORY DISCHARGE

NOTES: (1) RELEASES THROUGH VARIOUS OUTLETS MAY BE MODIFIED TO MINIMIZE DAMAGES OR OBTAIN ADDITIONAL BENEFITS.
(2) SUBJECT TO FIRST REMOVAL OF LOCAL RUNOFF.
(3) EXCEPT WHEN EXCEEDED BY LOCAL INFLOW.

Figure 3.1.2 Lake Okeechobee Regulation Schedule (adapted from U.S. Army Corps of Engineers, 1995)

Definition of Terms Used in Lake Management

In general, operational decisions and actions associated with managing lake water (when and how much water to release) are triggered by water levels in the lake and at some key gage locations in the Water Conservation Areas. The following terms are defined to clarify concepts behind the operations of Lake Okeechobee in the model.

- cutback stage: water level in Lake Okeechobee (LOK) below which Lake Okeechobee Service Area (LOSA) allocation will potentially be less than supplemental irrigation requirement; Supply-Side Management (SSM) is applied in this situation.

- cutoff stage: water level in LOK below which no water supply releases will be made; This restriction is not normally in effect but can be used if the simulated policy decision incorporates such a rule.

- import stage: canal level in a Water Conservation Area (WCA) at, or below which, environmental releases from Lake Okeechobee will commence

- floor elevation: stage at a canal or a gage location in a WCA at, or below which, no releases will be made from the WCA to the corresponding Lower East Coast Service Area (LECSA) unless an equivalent amount of water is brought in from LOK; Water supply releases from the WCA to the LEC must be balanced by inflows from LOK.

Lake Management Algorithm

The overall algorithm for simulating water releases from Lake Okeechobee is given in pseudo-code format. Each module referred to in the following discussion corresponds to one or a set of FORTRAN subroutines in the model.

1. Define key gages (monitoring point and/or canal) in WCAs and corresponding reference/trigger stages.

conservation area	reference stage to be computed based on the following:
WCA-1	if stage at gage 1-8T > land surface elevation at gage 1-8, then, use **1-8T** gage **or** if stage at gage 1-8T <= land surface elevation at gage 1-8, then, use stage at rim canal **CA1** (**CA1** represents L-40/L-7/L-39 borrow canals as a single canal reach in the model.)
WCA-2A	if stage at gage 2-17 > 11.5 ft NGVD, then, use **2-17** gage **or** if stage at gage 2-17 <= 11.5 ft NGVD,

then, use stage at L-38 borrow canal (denoted as **CA2A** rim canal in the model)

WCA-3A use 3-gage (3-3, 3-4 & 3-28) average stage, or optionally, stage at rim canal **CA3** (**CA3** represents L-38W/L-68A/C-123/L-67A/L-29 borrow canals as a single canal reach in the model.)

note: For WCA-1 and WCA-2A, the choice of reference gage essentially states that if the stage at the monitoring point or observation well goes below ground level, then the canal stage is used as reference. For WCA-3A, the selection is user-defined.

2. Compute conveyance capacities for all major EAA canals.

EAA conveyance calculations are based on look-up tables prepared from HEC-2 (USACE, 1990) runs with varying combinations of discharge, upstream stage and downstream stage (refer to Sec. 3.3). The following tables show pump, spillway and hurricane gate capacities as used in the model.

Table 3.1.2 EAA Pump Capacities

Pump	Capacity, cfs
S-3	2,580
S-2	3,600
S-8	4,170
S-7	2,490
S-6	2,925
S-5A	4,800

Table 3.1.3 EAA Spillway Capacities

Spillway	Capacity, cfs
S-8	$520 \times (HW-TW)^{0.5}$
S-7	$680 \times (HW-TW)^{0.5}$

note: Spillway capacity equations assume submerged controlled weir condition with gates fully open.

Table 3.1.4 Lake Okeechobee Hurricane Gate Capacities

Hurricane Gate	Capacity, cfs
S-354 (formerly HG-3)	2,000
S-351 (formerly HG-4)	2,400
S-352 (formerly HG-5)	900

notes: 1. The values given above are based on design discharges as defined in the EAA Atlas (Cooper, 1989) and structure books maintained by Data Management Division.
2. In the model, the maximum allowable discharge through a hurricane gate is the lesser value between the design capacity listed above and the flow capacity determined by the maximum allowable gate opening which, in turn, vary as a function of upstream and downstream stages.

3. Calculate required demands for the entire Lake Okeechobee Service Area.
Demands may be calculated within the model or read-in as pre-processed data (Trimble, 1992a and 1992b).

LOSA	Source
a. North Shore	assumed to not change in the model; equal to 1.5% (based on area) of total normal water use for entire LOSA.
b. Caloosahatchee River	pre-processed data; C-43 basin demand and runoff are previously estimated (Trimble, 1993).
c. St. Lucie River	pre-processed data; C-44 basin demand and runoff are previously estimated (Van Zee, 1994).
d. EAA	calculated in the AGAREA subroutine.

4. Check Lake Okeechobee stage.

If stage is within the Supply-Side Management (SSM) Zone (at least in lower Zone A in Fig. 3.1.3), then,

a. execute Supply-Side Management module which limits amount of irrigation to LOSA based on projected end-of-dry-season LOK stage and pre-processed normal LOSA demands (refer to Sec. 3.2).
input to module: current lake stage, day and month number, total LOSA demand for the day, previous day lake delivery to the LECSAs
output from module: portion of demand that can be met by the lake based on current lake storage (In the model, this is referred to as allocation.)

b. reduce LOSA demand to what can be satisfied by the lake as calculated in the SSM module.
note: The supply-side management line, as seen by the model, represents the line separating the supply-side management Zone A and warning zone as defined by Hall (1991). Thus, the SSM zone refers to any stage below the SSM line (Fig. 3.1.3).

else, continue.

5. Execute St. Lucie module (discussed at the end of this section).

input to module: C-44 basin demand, C-44 basin runoff, St. Lucie tributary runoff, St. Lucie estuary minimum demands
output from module: portion of C-44 runoff that goes into St. Lucie estuary and into Lake Okeechobee as backflow, release from LOK to satisfy C-44 basin demand and minimum St.

Lucie estuary demand, if any.
In general, the module can set priorities between:

a. satisfying minimum St. Lucie estuary demand (environmental delivery)
b. routing runoff, if any, from C-44 basin to LOK or to the St. Lucie estuary or satisfying C-44 basin demand from the lake. The following structure capacities are used: Port Mayaca Lock and S-308 spillway: 14,800 cfs; St. Lucie Lock and Dam at S-80: 16,900 cfs.

6. Execute Caloosahatchee (discussed at the end of this section).

input to module: C-43 basin demand, C-43 basin runoff, S-235 inflow, Caloosahatchee estuary minimum demands
output from module: portion of C-43 runoff that goes into Caloosahatchee estuary and into Lake Okeechobee as backflow, release from LOK to satisfy C-43 basin demand and minimum Caloosahatchee estuary demand, if any.
In general, the module can set priorities between:

a. satisfying minimum Caloosahatchee estuary demand (environmental delivery)
b. routing runoff, if any, from C-43 basin to LOK or Caloosahatchee estuary or meet C-43 basin demand from the lake. The following structure capacities are used: S-77 = 9,300 cfs; W.P. Franklin Lock and Dam at S-79: 28,900 cfs.

7. Calculate non-regulatory flows (water supply through WCA to LECSAs and/or environmental deliveries to WCA) flows from Lake Okeechobee.

There are generally two factors that influence water supply or environmental releases from Lake Okeechobee to the WCAs and from one conservation area to another: type of trigger (canal or nodal trigger) and release type (import or export).

Triggers based on canal stages (canal triggers) are used if a volumetric estimate is required to quantify the amount of water to be released. By performing a canal water budget using rainfall, overland flow and ET for the next time step, the model can “anticipate” the amount of water necessary to bring any canal to a required water level at the next time step since only a mass balance approach is used to simulate canal stages in the model (refer to Sec. 2.5). Triggers can also be based on groundwater levels at specific locations, i.e., a particular grid cell in the model. With this type of a trigger (nodal trigger), the model cannot make an accurate estimate of the volume of water necessary to bring the groundwater up to the required level since groundwater levels are simulated in the model based on the continuity (mass balance) and momentum equations (refer to Sec. 2.4). Changes in groundwater levels cannot be “anticipated” as well as canal levels. In other words, the quantity of water needed to affect a specific response in the aquifer is a much more complex process than making volume calculations needed to raise a canal level. If the trigger is a node, the model makes a release from an upstream source through the appropriate canals and structures, limited by the conveyance capacities of the hydraulic facilities. An evaluation of the water level at the trigger location is necessary at the beginning of the following time step in order to check if the required water level is met or not.

Another factor to consider in making water supply or environmental releases within the model is the type of release itself. After a canal or nodal trigger sends off a signal within the model, an import of water may be necessary to bring the stage at that trigger location to a required level. This situation creates a demand that has to be met from an upstream source (or a downstream source if pumping is allowed). Likewise, since the issue of environmental restoration hinges on the concept of balancing needs, the availability of exporting water from the source can also be triggered by a canal or nodal stage. Minimum water levels at canals or nodal locations can be specified in the model in order to not “overdrain” the source. This option restricts the timing of environmental releases from an upstream conservation area (or LOK), i.e., export stages can be set in the model such that water will not be made available at a downstream conservation area (or ENP), if the stage in the upstream source falls below such levels. Therefore, an import trigger triggers a delivery of water to bring the stage up to a particular level at the trigger location. On the other hand, an export trigger limits the amount of time when water can be removed from the vicinity of the trigger location so as not to overdrain this area. Section 3.4 elaborates on some of the implementations of environmental releases in the SFWMM.

Additional operational constraints associated with non-regulatory releases (water supply or environmental) from Lake Okeechobee are assumed in the model and are as follows:

1. Water supply releases are made from Lake Okeechobee:
    a. to its service areas are subject to supply-side management if no flood control backpumping from the EAA to the lake is being initiated; and
    b. to the south if:
        i. water supply requirements in the LEC exist;
        ii. water levels in the Water Conservation Areas are at or below their floor elevations; and
        iii. conveyance capacities within the EAA are not exceeded.
2. Environmental Releases from Lake Okeechobee:
    a. to the south if environmental needs in the Water Conservation Areas exist. In terms of required volume to deliver or stage to maintain at key locations within the WCAs, no environmental needs, to date, have gone through rule-making process yet. However, stages obtained from the Natural System Model (NSM) output are assumed to provide good estimates of environmental targets.; and
    b. to the estuaries as calculated in steps 5 and 6 if environmental needs in the St. Lucie and Caloosahatchee estuaries exist (Haunert and Chamberlain, 1994).

8. Update LOK stage.

9. Check LOK stage.

If stage is within higher regulatory zones (i.e., LOK stage in Zone A, B or C)
then, make regulatory releases. LOK regulatory flows can be diverted into anyone or all of the following destinations:

1. through S-352 via West Palm Beach Canal through S5A into WCA-1;

2. through S-351 via Hillsboro Canal through S6 into WCA-1;
3. through S-351 via North New River Canal through S7 into WCA-2A;
4. through S-354 via Miami Canal through S8 into WCA-3A;
5. through S-308 to St. Lucie River; and
6. through S-77 to Caloosahatchee River.

Due to the magnitude of a regulatory discharge through a single conveyance canal, the lake stage may drop to a level so as to significantly influence the amount of discharge through the next conveyance canal. For this reason, the model updates lake stage before it calculates the necessary release for the next conveyance canal in the list. The order by which releases into WCAs are made is input by the user. All regulatory releases (Fig. 3.1.2) are subject to the remaining or available capacities of the upstream structures (hurricane gates), downstream structures (pumps and spillways), and conveyance canals. Structure and conveyance capacities are reduced by the amount of water already discharged for non-regulatory purposes as defined in steps 5, 6 and 7. An additional constraint before any regulatory release can be made south of LOK is that no local runoff should exist in the EAA basin corresponding to the conveyance canal in consideration.

else, stage is in pulse zone (i.e., LOK stage in "Zone D")

then, make estuarine pulse releases, through S-77 and S-308, according to pulse release rules. Zone D is broken down into three levels (I, II and III), each one prescribing an outflow hydrograph (10-day duration release rule) of different magnitudes through the St. Lucie and Caloosahatchee rivers (Table 3.1.5). Once a 10-day outflow hydrograph is initiated at a pulse level dictated by the schedule, the release rule is continued to completion even if lake stage drops below that pulse level. After the initial 10-day period is completed, the need for additional releases will be evaluated.

else, LOK stage is at "normal operating zone" (i.e., LOK stage at "Zone E")

therefore, go to step 10.

10. Update LOK stage.

11. Return to main program.

Table 3.1.5 Pulse Release Hydrographs for the Three Levels of Zone D Regulation Schedule for Lake Okeechobee

DAY	St. Lucie I	St. Lucie II	St. Lucie III	Caloos. I	Caloos. II	Caloos. III
1	1,200	1,500	1,800	1,000	1,500	2,000
2	1,600	2,000	2,400	2,800	4,200	5,500
3	1,400	1,800	2,100	3,300	5,000	6,500
4	1,000	1,200	1,500	2,400	3,800	5,000
5	700	900	1,000	2,000	3,000	4,000
6	600	700	900	1,500	2,200	3,000
7	400	500	600	1,200	1,500	2,000
8	400	500	600	800	800	1,000
9	0	400	400	500	500	500
10	0	0	400	500	500	500

note: All values in cubic-feet per second.

Lake Interaction with the C-43 and C-44 Basins/Estuaries

As inferred in steps 5, 6 and 9 above, the lake uses the C-43 canal (Caloosahatchee River) and the C-44 canal (St. Lucie River) as conduits for releasing regulatory and non-regulatory flows west and east of the lake, respectively. Figure 3.1.4 is a schematic diagram of the Caloosahatchee basin/estuary simulation module as it relates to steps 6 and 9 above. Storage facilities such as reservoirs and ASRs in this area, as well as in the St. Lucie basin/estuary area, do not exist but can be simulated as an option in the model. For the Caloosahatchee (or St. Lucie) basin/estuary, the purpose of these facilities are:

1. to attenuate regulatory flows from the lake through structure S-77 (or S-308) which would otherwise be harmful to the basin (flooding) and to the estuary (sudden lowering in salinity);
2. to provide backup source of water for satisfying irrigation needs in the basin which otherwise comes exclusively from Lake Okeechobee; and
3. to regulate inflows to the estuary which may be deemed harmful to the ecology in the area.

Environmental protection and enhancement have been big issues in the Caloosahatchee and St. Lucie estuaries. In a way, the current regulation schedule (Trimble and Marban, 1988) provides

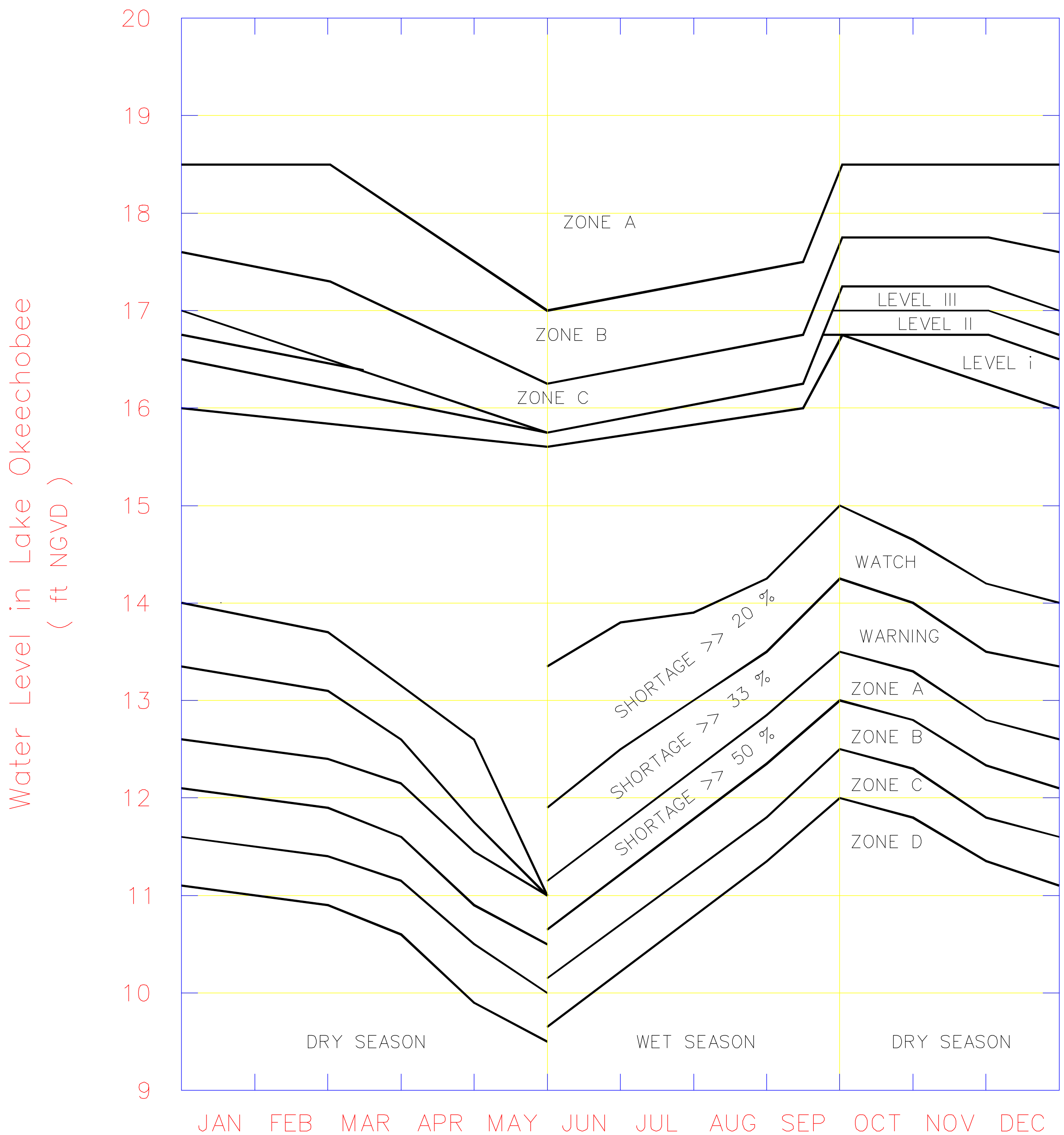


Figure 3.1.3 Overall Operating Levels for Lake Okeechobee

note: Lines above 15 ft NGVD define release management zones (Hall, 1992).
Lines below 15 ft NGVD define supply-side management zones (Hall, 1991).

some environmental protection to the estuaries. Incorporating a pulse zone (Zone D) reduces the flushing effect of lake regulatory flows by prescribing an outflow hydrograph that minimizes sudden fluctuations in salinity levels in the both estuaries. From an operational standpoint, the question being raised is: How can Lake Okeechobee releases (and possibly local basin runoff) be controlled in order to support a "healthy" environment for the Caloosahatchee and St. Lucie estuaries? A healthy environment implies an environment that supports a diverse ecosystem: oyster, shoalgrass, tapegrass, and many other communities. Possible approaches which are implemented as options in the model are:

1. Follow a target distribution of inflows to the estuaries;
2. Test LOK regulation schedules that minimize impacts to the estuary; and
3. Provide additional detention facilities both above ground (reservoirs) and below ground (Aquifer Storage Recovery systems) that will reduce or attenuate runoff coming from the C-43 and C-44 basins as well as regulatory discharges from Lake Okeechobee.

Aquifer Storage and Recovery (ASR) systems are being investigated as alternative storage facilities in the Lower East Coast Regional Water Supply Plan (SFWMD, 1995; CH2M-HILL, 1995). The operating rules and procedures associated with ASRs are discussed in Sec. 3.3.

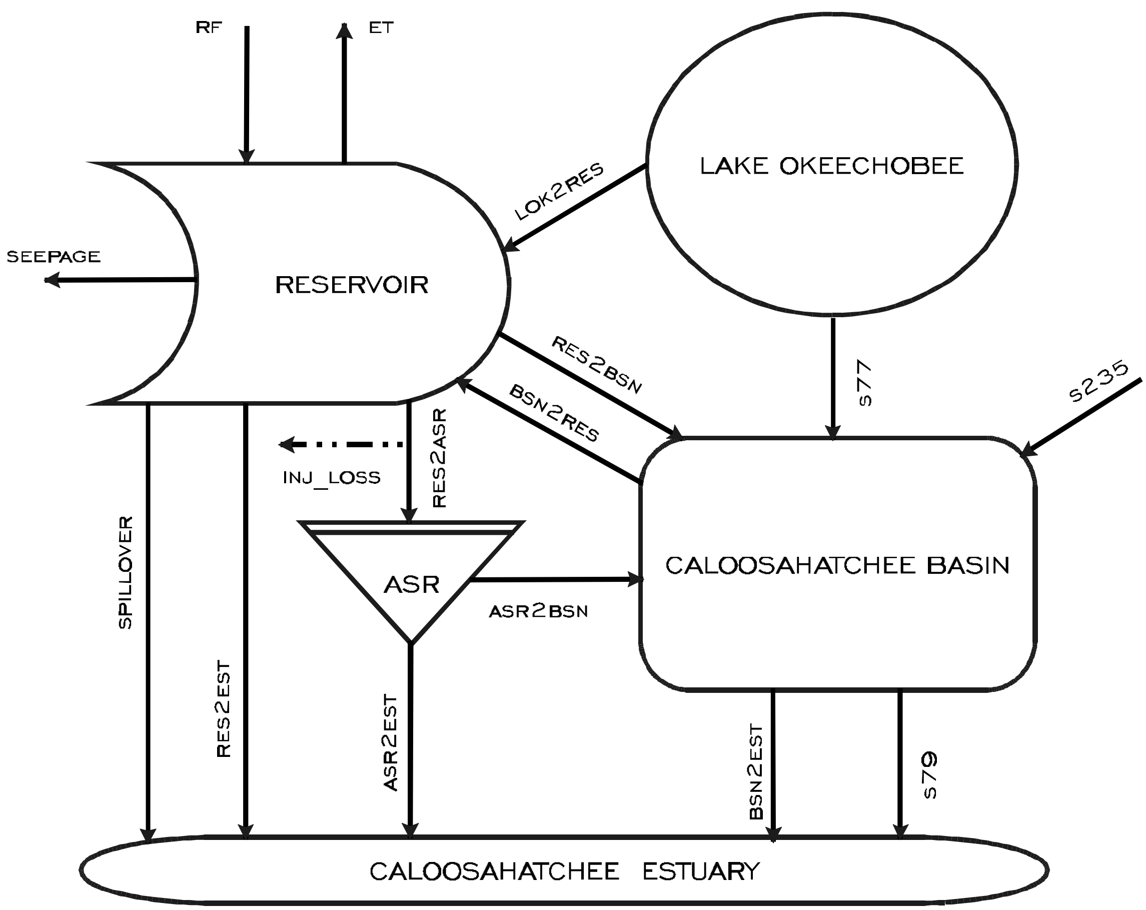


Figure 3.1.4 Schematic Diagram of Caloosahatchee Basin/Estuary Simulation Module